# Tide-triggered tremors give clues for earthquake prediction

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## Low-frequency signals reveal San Andreas Fault weakens with depth

LOS ALAMOS, N.M., July 21, 2016—The triggering of small, deep earthquakes along California's San Andreas Fault reveals depth-dependent frictional behavior that may provide insight into patterns signaling when a major quake could be on the horizon, according to a paper released this week by the Proceedings of the National Academy of Sciences (PNAS).

The study, which was led by the U.S. Geological Survey and Los Alamos National Laboratory, reports that the deepest part of California's 800-mile-long San Andreas Fault is weaker than expected and produces small earthquakes in response to tidal forces.

“These findings provide previously inaccessible information about the San Andreas Fault activity and strength,” said Los Alamos National Laboratory’s Paul Johnson, a coauthor on the paper and geophysicist in the Lab’s Earth and Environmental Sciences Division. “The study’s discovery of low-frequency-earthquake (LFE) and tidal triggering of the San Andreas Fault gives seismologists new warning signals and information about slightly more predictable triggers of quakes to come.”

Los Alamos maintains technical expertise in seismology and the behavior of Earth’s crust as a part of its role monitoring underground nuclear testing globally and applies that expertise to other national challenges, including earthquakes.

The team used a data set of 81,000 LFEs since 2008 to match LFEs to tides. They determined in addition to being modulated with the semidiurnal (twice daily) tides, LFEs are also modulated by fortnightly tides. The contrasting relationship between the LFE responses observed at two different tidal timescales should serve as a powerful constraint on understanding frictional behavior and stress transfer on the deep San Andreas.

“The findings provide new information regarding the fault zone structure with depth,” Johnson said. The authors found that deep, small, low-frequency earthquakes (LFEs) on the San Andreas Fault are most likely to occur during the waxing period approaching a full or new moon within the fortnightly tide period of 14.7 days. The fortnightly tide modulates the semidiurnal (twice a day) tide. LFEs preferentially occur not when the tidal amplitude is highest, as might be expected, but when the tidal amplitude most exceeds its previous value, the authors found. LFEs correlate more strongly with larger-amplitude shear stress.

Previous studies have found stronger tidal semidiurnal variation for deeper, continuously active LFE families. The team used two models to explain variations: One, based on friction studies, posited LFEs occur when stress accelerates slip. The other model suggests LFEs occur by simple threshold failure but are driven indirectly by tidally modulated creep. Regardless of which tidal triggering model is correct, the inverse relationship between the strength of the semidiurnal and fortnightly modulations provides a key insight into the mechanics of LFEs and the structure of the deep fault, according to the paper.

“The pattern of LFEs tells us something about loading rates and stress conditions in the deep part of the fault,” said Andrew Delorey, a seismologist with Los Alamos. “We don’t know to what extent the deep part of the fault where LFEs occur is coupled to the shallow part of the fault where regular earthquakes occur. We may find that as stress increases and approaches failure in the shallow fault, where large earthquakes occur, it will affect the pattern of LFEs in a way that allows us to use LFE behavior to infer conditions in the shallow fault.”

While tidal triggering of earthquakes is found only for select environments, triggering of tremor has been found almost everywhere that tectonic tremor is observed, generating insights into the mechanics of the brittle transition zones. The response to the tidal stress carries otherwise inaccessible information about fault strength and rheology.